An ENSO predictor of dust emission in the southwestern United States

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[1] Here we show that there is a significant relationship between Nino 3.4 ENSO anomaly (Dec–Jan average) and precipitation in the southwestern United States. This contributes to increased frequency of dust events in the years following strong La Niña and El Niño years. High probabilities (60%–100%) exist for an elevated frequency of dust events in years when the ENSO anomaly, annual precipitation, or annual P/PE falls below the 10th percentile. This analysis provides a quantitative framework in which to evaluate the expected effects of climate change on this and other arid regions. *INDEX TERMS:* 0305 Atmospheric Composition and Structure: Aerosols and particles (0345, 4801); 1610 Global Change: Atmosphere (0315, 0325); 1625 Global Change: Geomorphology and weathering (1824, 1886); 1809 Hydrology: Desertification; 1854 Hydrology: Precipitation (3354)

1. Introduction

[2] Wind erosion is a principal agent of geomorphology and land degradation in arid regions. It also produces dust that can have regional and global effects. Mineral aerosols may impact global climate through their ability to scatter and absorb light [*Sokolik and Toon*, 1996]. Dust is thought to play a major role in ocean fertilization and CO_2 uptake [*Piketh et al.*, 2000]. Deposition of dust can be important for soil formation and nutrient cycling [*Reynolds et al.*, 2001] and serious public health concerns arise in regions affected by high concentrations of atmospheric dust [*Griffin et al.*, 2001].

[3] In the southwestern U.S., the fine-grained wind erodible sediments and the dry climate have created a situation in which wind erosion may severely affect the area [*Okin et al.*, 2001]. The purpose of this research is to identify ENSO-related climate conditions that increase the probability of severe wind erosion in the southwestern U.S. and to determine ENSO and climate thresholds beyond which dust emission increases dramatically. Spatial and temporal variability characterizes the climate of the world's drylands and can be used to probe the response of the environment to changes in global or regional climate. Although the southwestern U.S. is not a major global dust source, we have concentrated our analysis here due to the availability of high-quality data. The analysis technique presented here for the arid U.S. is transportable to other areas of greater dust production.

2. Methods

[4] Data on dust events, defined as sustained wind erosion events that loft dust into the boundary layer and reduce visibility to below 11 km, were compiled for four NOAA COOP stations in southwestern U.S. deserts for the period 1973 to 1999 using the method of *Bach et al.* [1996]: Daggett (Barstow), California; Las Vegas, Nevada; Tucson, Arizona; and Albuquerque, New Mexico. Precipitation, temperature, wind speed, potential evapotranspiration (PE) [*Thornthwaite and Mather*, 1957], and the ratio of precipitation to PE (P/PE) data were also compiled for these stations. Finally, the average December–February (DJF) Nino 3.4 ENSO anomaly data were compiled for the same years (http://ingrid.ldgo.columbia.edu/). Pearson's or Spearman's rank correlation coefficients were calculated for all pairs of variables, separately for each station as well as for averages of all stations, for the time period including lag effects (e.g. ENSO anomaly vs. precipitation, precipitation vs. the following year's dust events) and tested for significance using the method of *Sokal and Rohlf* [1981].

3. Results and Discussion

[5] Our results indicate that there is a significant (p-values <0.05) positive correlation between total November–March precipitation and DJF ENSO anomaly for all stations (Figure 1). This correlation is consistent with findings of previous authors [*Mason and Goddard*, 2001]. The correlation between DJF ENSO anomaly and annual precipitation is generally weaker due to the lack of correlation between summer precipitation and ENSO strength, particularly for the Tucson and Albuquerque stations which receive a significant amount of their rainfall during summer monsoons. No correlations or trends were detected between the DJF ENSO anomaly and wind speed, temperature, or potential evapotranspiration.

[6] Grass cover in the study areas tends to increase during periods of high precipitation. Senescent grass can persist for at least one year and is the primary temporal control on wind erosion [*Helm and Breed*, 1999; *Peters and Eve*, 1995]. Precipitation, especially in the winter and spring, has been shown here to be correlated with the DJF ENSO anomaly. Therefore, we expect wind erosion to be anticorrelated with DJF ENSO anomaly. Dust event data for each station display non-normal distributions and high inter-station variability that when untransformed, are intractable with standard statistical tests. Thus, we computed the average normalized rank of dust events for all stations for each year. These data are independent from and approximately identically distributed with ranked ENSO anomaly data and can thus be subjected to statistical testing.

[7] There is a significant negative correlation (Figure 2; p-values < 0.05) between the average normalized rank of dust events and preceeding DJF ENSO anomaly (comparing, for example, 1990 average normalized rank of dust events with December, 1988–February, 1989 ENSO anomaly).

[8] This correlation is notably violated in two years that correspond to years following strong ENSO years (1983–84 & 1998–99: DJF Nino3.4 index >2.0). Recent studies have emphasized the nonlinear response of teleconnections during extreme ENSO events suggesting that responses during these years may be different from non-extreme years [*Hoerling et al.*, 2001].

[9] Wind erosion in the southwestern U.S. tends to occur mostly in the winter and spring months [*Bach et al.*, 1996], and our own data confirm that November–March precipitation is positively correlated with DJF ENSO anomaly. In addition, there is a one-year lag between La Niña years and increased dust event frequency (Figure 2). We interpret this relationship between ENSO and dust events to result from suppression of winter vegetation production

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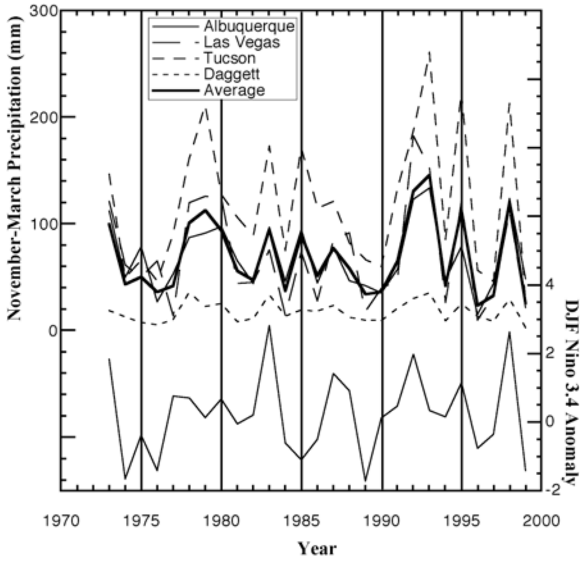

Figure 1. November–March precipitation for all stations and DJF Nino 3.4 anomaly for the period 1973–1999.

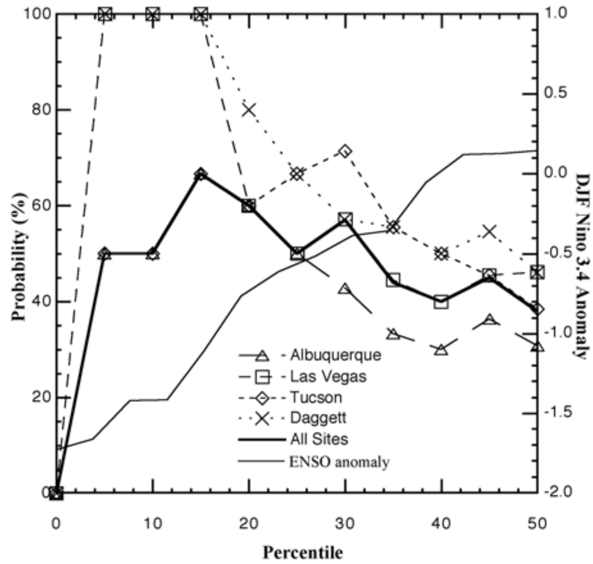

Figure 3. Probability that a station's dust event frequency will be greater than the median for that station given that the previous year's DJF Nino 3.4 anomaly is less than a certain percentile. The line labeled "All Sites" is calculated using the average normalized rank of the number of dust events for all stations. The thin solid line that increases from left to right across the diagram is the cumulative distribution function for the DJF Nino 3.4 anomaly data from 1973–1999.

due to decreased precipitation during La Niña years. This condition of low standing biomass (live or senescent) continues until the following winter and spring when generally strong winds associated with storms cause wind erosion before the height of the next year's growing season [*Bach et al.*, 1996]. During moderate El Niño conditions, vegetation greening can occur quite rapidly after rains, but the one-year lag effect is due to high amounts of standing senescent biomass that persists through the next dust storm season. In contrast, the anomalous increases in dust event frequency associated with the strongest El Niño years (1984, 1989, Figure 2) are probably due to increased delivery of material to or reworking of material deposited in closed basins during these very wet years when individual storms can be large and intense [*Reheis and Kihl*, 1995].

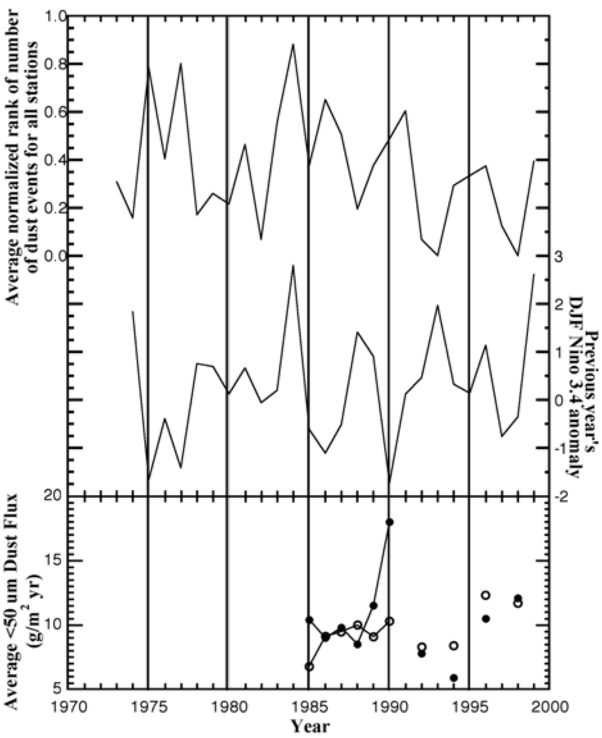

Figure 2. Anticorrelation between dust storm frequency, dust flux, and the previous year's DJF Nino 3.4 anomaly. Dust flux measurements after 1990 are biannual and values shown here represent 2-year averages. Closed symbols represent the average of four sites downwind of Barstow, CA. Open symbols represent the average of two sites near Las Vegas, NV.

[10] The negative correlation between DJF ENSO anomaly and wind erosion is corroborated by other datasets. Using remote sensing analysis of an area undergoing severe wind erosion in the Mojave desert (near the Daggett COOP station), *Ray* [1995] has reported 1981, 1984 and 1990 to be years of severe wind erosion. In addition, he noted a pulse of wind erosion sometime between 1985 and 1988, but lacked data to constrain this pulse further. These periods correspond to peaks in average ranks of wind events in Figure 2.

[11] Dust deposition rates (fluxes) measured at sites within the southwestern U.S. may also be used to corroborate the relationship between the ENSO anomaly and dust storm frequency. Using the methods of *Reheis and Kihl* [1995], fluxes of <50 mm dust were measured at eight sites throughout California annually until 1989 [*Reheis and Kihl*, 1995] and biannually thereafter (this report). This dataset corroborates a pattern of relatively high dust event frequency in 1990 following a strong El Niño and in the period 1994–1996 with relatively low dust event frequency in intervening years. In addition, the desiccating effect of 1988–1989 La Niña shows up prominently in the dataset as a significant peak in <50 mm dust flux in 1990 whereas the relatively wet El Niño event of 1991–1992 appear to be associated with a suppression of dust production in 1993–1994.

[12] In order to determine ENSO-related thresholds and to convert the relations reported here into predictions for the future, conditional probabilities were calculated by asking the question: what is the probability that a station's dust events for a year would be greater than the median for that station, given the fact that the previous year's DJF Nino 3.4 anomaly was less than the

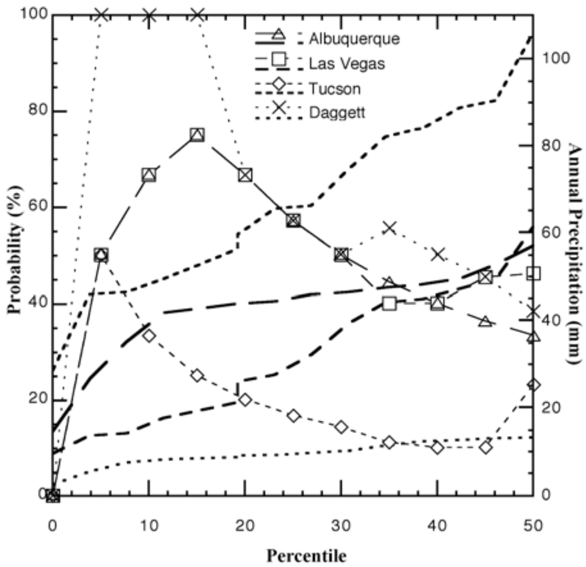

Figure 4. Probability that a station's dust event frequency will be greater than the median for that station given that the previous year's precipitation is less than a certain percentile. The heavy lines that increase from left to right across the diagram are the cumulative distribution functions for annual precipitation data for each station from 1973–1999.

10, 20... 50 percentile? Conditional probabilities were also calculated by asking: what is the probability that a station's dust events for a year would be greater than the median for that station, given the fact that the previous year's precipitation or P/PE was less than 10, 20.... 50 percentile? The results of this exercise provide quantitative estimates of the probability of greater-than-normal wind erosion can be expected given future Nino 3.4 predictions or measurements (Figures 3 and 4. Results for P/PE not shown but are nearly identical to precipitation results). For example, if the DJF, 2002–03, Nino 3.4 anomaly is −0.76 (20th percentile) we can expect that the number of dust events will be greater than the median for all sites (with 80% probability for Daggett and 60% probability for Las Vegas, Tucson, and Albuquerque). Thus, our results indicate therefore that a climate change related decrease in annual precipitation for the southwestern United States will most likely be associated with a significant increase in the frequency of dust storms and the health, safety, and environmental hazards that they present.

4. Conclusions

[13] Spatial and temporal variability characterizes the climate the world's drylands. This variability can provide leverage in understanding the environment's response to climate change. The results presented here provide a quantitative framework to evaluate the effects of future climate change on wind erosion and dust emission in the southwestern U.S. Climate models indicate that global warming may be associated with desiccation of the world's temperate deserts [*Hansen et al.*, 1988] or with increases in El Niño frequencies [*Timmermann et al.*, 1999] while atmospheric CO_2 concentrations are expected to increase [*Polley et al.*, 1997]. Desiccation is likely to lead to increased dust storm frequency while increased moderate-strength El Niño frequency and CO_2 fertilization will suppress wind erosion in the region. With the results and methodology presented here bounds can be placed on the probability that these regional climate changes will be associated with increased dust emissions and the related health and environmental concerns.

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